The Channeling (Microventing)Phenomenon in Young Marine Sediments

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LONG-TERM GOALS

To understand, evaluate, and quantify physical and oceanic processes involved in the erosion, deposition, and transport of sediments. This involves short-term and long-term effects, and characterization of those effects based on sediment source and fluid mechanics. The outcome of this work will be a deeper understanding of the processes involved, and further development of predictive capabilities.

OBJECTIVE

Understanding the mechanics of microventing is of paramount importance to identify the sediment properties and flow threshold conditions that trigger the formation of fluid vents in the subsurface of young (recently deposited) sediments, and for developing a quantitative model that predicts the onset of venting formation and propagation and their effects on settling of suspending aggregates. Knowledge of channel formation can be used to elucidate the mechanisms involved in the stability of young sediments. Such information will be useful to scientists and engineers in several disciplines, including those focusing on the prediction of fate and transport of contaminated sediments and those focusing on the refinement of existing remediation techniques in riverine and estuarine systems (Papanicolaou and Maxwell, 2002). The overall scope of this investigation is to describe the microventing (aggregative fluidization) process in pure clay sediments and in young marine sediment deposits. The specific objectives of this project are:

1. Develop the appropriate instrumentation required for the proposed experimental set-up.
2. Identify the conditions under which microventing occurs. This will involve determining the sediment concentration ranges at the sediment-suspension interface when commencement of microventing occurs. Determine the pore pressure distribution and effective stress when microventing forms.
3. Estimate the effects of microvents on sediment strength.
4. Develop a numerical model applicable to low stress conditions (less than 10 atm) to study the effects of microvents on the settling process of suspended aggregates.

APPROACH

Various means of determining sediment concentrations exist, both intrusive and non-instrusive methods. In laboratory studies, a non-intrusive method is preferred, as this allows continued formation of sediment structure, which is particularly important in underconsolidated sediments (Font, 1988). Intrusive methods, such as core sampling or OBS (Optical Backscatter Sensors) work well for field environments, where the scale of the test region is large. For laboratory use, simple grab samples are used (Vesilind and Jones, 1993), as is conductivity testing (Holdich and Butt, 1995), but the disadvantage to this sampling technique is that some of the fluid volume is removed from the test, and it also does not work in the consolidating region. A third method, which works well for consolidating sediments, is to use radiation (Cesareo et al, 1993; Hopmans and Dane, 1986; Been and Sills, 1981). X or γ radiation may be used, each having its pros and cons. However, the principle is the same, according to Beer's Law (1),

$$I(x) = I_o e^{-\mu x} \tag{1}$$

where I is radiation intensity (counts per second), μ is the attenuation coefficient, and x is the thickness of the medium. This principle is valid for a beam of monoenergetic radiation, as the attenuation coefficient is a function of the specific energy of the radiation source. As photons pass through a medium, they are attenuated, but their energy remains constant; they either stop due to interactions with matter, or pass through (Leo, 1994). There are three types of interactions, namely, the photoelectric effect, Compton scattering, and pair production (Leo, 1994), all of which are energy dependent for a given material. Attenuation coefficients, therefore, are a function both of the material and the energy of the radiation. Mr. Adam Maxwell, graduate research assistant, has investigated the use of radiation scanning thoroughly, as it is complex to apply properly and potentially dangerous.

A pore fluid pressure measurement system, using minitransducers with very high stability over extended time periods, is used to measure pore pressure characteristics of the consolidating clay. A custom designed, sintered metal or ceramic filter is used to support the pressure of the solid matrix, and only pass the fluid pressure to the transducer. The filter may be interchanged with a variety of sizes; 0.5, 1, and 2 micron filters are currently in use. Air is removed from the assembly using a vacuum pump, to avoid fluctuations in pressure due to air bubbles on the sensor diaphraghm. Mr. Maxwell is also involved in the design and calibration of this system, and is responsible for analysis of results.

For purposes of visualization, a high-speed industrial digital camera is used. A zoom lens capable of very high magnification is used with this camera. This may be triggered by the computer program which runs the measurement system, or it may be triggered manually or by an intervalometer. In this portion of the experimentation, Mr. Maxwell is working with Zhiqiong Hou, another graduate research assistant, to explore the visualization techiques used and develop a rigorous qualitative and quantitative methodology for testing. Zhiqiong will apply the laboratory data to the numerical component of this study.

WORK COMPLETED

A measurement system following the principles described above has been constructed, and is under calibration and testing. In practice, a radiation source is mounted on a vertical, motorized traverse (Figure 1), and a sensitive detector is mounted diametrically opposite the source. A medium (in this case, an acrylic cylinder containing the clay/water suspension) is placed between the source and detector, and the intensity of the source after attenuation is measured and compared to a baseline.

Figure 1. Photograph of traversing setup, with detector and radiation source in place.

One of the radiation sources acquired for this purpose is a 570 mCi ^{241}Am gamma source (60 kev photon), which has the advantage of a long half-life (453 years), so will maintain a constant radiation level over time. It also requires little shielding, and is relatively safe. However, it is a low energy photon, and easily attenuated by a dense mixture of kaolinite and water; it also emits the 60 kev gamma during only 40% of its disintegrations, reducing its effective intensity by 60% (a 26 kev gamma is also emitted, but is entirely attenuated). A second source is being obtained, with a higher energy; it is 0.51 mCi of ^{60}Co, which has two pure gamma transitions, at 1.17 and 1.33 Mev. According to calculations, the higher energy source will have a higher count rate when attenuated by a kaolin mixture, in spite of its lower activity. This will result in better counting statistics over a shorter period of time. However, it requires more shielding than the low energy source (lead rather than brass), and a new collimator and detector shield were custom machined out of lead bricks. The radiation level is measured by a Harshaw 6S2/2-X NaI(Tl) scintillation detector mounted opposite the source, and raised simultaneously with the source by the stepper motor on the traverse. The Nuclear Instrumentation Module setup uses a Harshaw NV-32A high voltage power supply for the photomultiplier tube in the scintillation detector, and the signal is amplified by a Harshaw NB-11 preamp and NA-17 amplifier. Signal analysis is provided by a Harshaw NC-22 single channel analyzer (SCA), and an NS-30 scaler is used as a counter. The single channel analyzer allows selection of only one radiation energy level, so the requirement of monoenergetic radiation for Beer's Law is met by using this as a bandpass filter. The SCA must be used to filter the lower energy, particularly with the ^{60}Co source, or count rates will be in error.

The traversing system is moved by a high-torque step motor, and is capable of 2 meters of vertical travel with rapid acceleration. The nuclear instrumentation is controlled by a custom developed computer program, which also controls the step motor to move the source and counter. The computer also controls the Hewlett Packard 3497A data acquisition unit which is used to scan pressure transducers, and it can also trigger a digital camera.

The numerical modeling component of this study is being investigated simultaneously with the experimental component. The majority of the existing one-dimensional (1-D) consolidation models are applicable to large stress regimes with limited use to low stress conditions (stress less than 10Atm) (Den Haan, 1992). These models typically underpredict the time required for the compaction of sediments and do not provide accurate predictions of the density and pore pressure distributions when infinitesimal strains occur. This is the case, for example, in estuarine environments, during the consolidation process of newly –deposited marine sediments due to self-weight consolidation of sediments.

The numerical component of this research focuses on the modeling and simulation of the self-weight consolidation process of newly-sediment deposits occurring in a vertical sedimentation column for low stress values. It describes the derivation steps of the governing equation in an Eulerian coordinate system where material deformation is referenced to the impermeable bottom of the sedimentation column. This work utilizes the constitutive relations developed by Tiller and Khatib (1984) that express the dependency of the material properties (such as volume fraction and permeability) to the effective stress for low stress levels less than 10 atm. Geotechnical investigators have proposed several constitutive models for the compression behavior of pure clays, however, nearly all of them relate only the void ratio to changes in effective stress and are useful for the high stress regime (e.g. Butterfield 1979, Carrier 1985, Liu and Znidarcic 1991, Den Haan 1992). The self-weight consolidation equation presented herein, is a second order nonlinear transient partial differential equation of the parabolic type (Papanicolaou and Diplas, 1999). In order to solve the equation, two constitutive equations relating both volume fractions of solids and intrinsic permeability with effective stress are required. Geotechnical investigators have proposed several constitutive models for the compression behavior of clay in 1-D consolidation. Nearly all of them relate void ratio, e to the changes in effective stress (e.g. Butterfield 1979, Carrier 1985, Liu and Znidarcic 1991). Den Haan (1992) presented a unified relationship for the e vs. σ' models. Most of these models are useful for the high stress regime. Similarly, a number of models that relate permeability to void ratio have been proposed (Pane and Schiffman 1997). In this study, however, another type of model proposed by Tiller and Khatib (1984) that relates volume fraction of solids, ε_s, to the effective stress σ' and intrinsic permeability K to the effective stress, σ' is used. This model has been found to be useful for the low stress levels less than 10 atm.

The constitutive models proposed by Tiller (1981) and Tiller and Khatib (1984) are based on settling tests of slurry columns. The soil coefficients presently used in the model have been determined from regression analysis on experimental data of a wide range of materials, including attapulgite, latex, perlite, calcium carbonate, and kaolin (Tiller 1985). Therefore, the constitutive model is generally applicable for most particulate materials.The governing equation is a nonlinear, transient partial differential equation derived in the Eulerian coordinate system. The equation is solved numerically using a hybrid combination of finite element and the finite difference methods.

RESULTS

A significant review of literature was accomplished. This led to the development of a testing methodology for quantitative and qualitative laboratory experiments. These experiments are underway, after overcoming significant technical and administrative details, particularly with respect to the use of nuclear radiation. The principles of soil mechanics and geotechnical engineering will be applied to the experimental study and to the numerical model which is under development by refining an existing code base.

IMPACT/APPLICATIONS

This investigation is in line with the general goals of the EuroSTRATAFORM, in particular in the understanding of: 1) the processes that control the erosion, transport and deposition of sediments, 2) the physical processes responsible for post-depositional modification of seabed strata, and 3) the processes responsible for the creation of preserved stratigraphic architecture, including spatial and temporal heterogeneities, in sedimentary formations.

TRANSITIONS

The research will help the modelers (e.g., James Syvitski, Friedrichs) to improve current modeling efforts by providing information about the mechanical or constitutive behavior of the weak sediments before and after microventing occurs. By studying here the microventing process of under-consolidated sediment layers, the rheological parameters (yield stress and plastic viscosity) of young sediments will be determined which will be used as input parameters to the models.

RELATED PROJECTS

The results of the investigation will be coupled with the findings obtained from the field collaborators. Specifically, in-situ measurements of soil properties, rheology and settling will be compared against the lab measurements. In contrast to the Eel margin (which was the STRATAFORM study site) where the seabed is stable, the two European study areas (the Adriatic Sea at the exit of Po River, and the Gulf of Lions at the exit of Rhone River) contain evidence for numerous failures upon young (under-consolidated) sediments, which appear to be partly related to microventing. The laboratory results will provide information about the transient variation of the porosity and pore pressure distribution under different initial conditions, something that is not feasible to obtain at the field. The PI works closely with the field team of Chuck Nittrouer, who they will provide sediment data from both sites. Also, Homa Lee and J. Locat will team up with the PI to compare their findings on bed and bank failure. Nabil Sultan from the European Team will be also an active participant in the project helping with the analysis of soil properties.

PUBLICATIONS

Muhunthan, B. Papanicolaou, A.N. and Chin, K.H. "A Nonlinear Model For Small-Strain Consolidation." Submitted to the *International Journal of Numerical and Analytical Methods in Geomechanics*, 2002

Maxwell, A., Papanicolaou, A.N., and Yonge, D. (2002) "Micro Venting (Channeling) in the Subsurface Interface: Environmental Implications." Presented at the INRA Subsurface Science Symposium, October 13, Boise, ID.

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